Loch Leven flushing for control of algal blooms

-potential for exit sluice management for better delivery of ecosystem services

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Executive Summary

- This report forms part of the delivery for the 2016-2021 Scottish Government funded project: Payments for Ecosystem Services – Lessons.
- Water levels in Loch Leven, Scotland have historically been governed to deliver managed flows for downstream industry. Some of the management rules could be updated to better reflect current stakeholder demands, and potentially to deliver a Payments for Ecosystem Services scheme.
- A separate report documents the potential for reducing the prevalence of algal and cyanobacterial blooms through increasing flushing rate in early summer, as shown with the model PROTECH for 2005.
- This report describes a *proof of concept* analysis of outlet sluice gate management changes that would deliver the required changes in early summer flushing rate.
- The hydrological and hydraulic calibration of a model of the Loch system is described, focusing on the year 2005. The model uses area adjusted inflows and hydraulic modelling of the outlet sluice gate management.
- Calibration was hampered by uncertainty about the number of gates open in the 2004-2005 management dataset, but a calibrated model which adequately reproduced observed loch levels and outflows was obtained.
- This calibrated model was used to explore how best to achieve a 15% increase in flushing rate for 10-20d from day 190 and finds that the gate management changes need to begin about 10d prior to the target onset of increased flushing.
- Further work would focus on improved calibration over a longer time period, development of a forecasting based approach, as has been achieved for Lunan Water in another part of the

Introduction

Loch Leven is located in the lowlands of east central Scotland. The catchment drains an area of 145 km^2 and the loch has an annual water retention time of about 5 months [1]. The catchment is composed chiefly of Old Red Sandstone overlain by glacial deposits. The Loch has historically been operated to deliver managed flows for downstream industry (such as paper mills) and abstraction for drinking water, while considering the interests of loch users and riparian landowners. With the demise of the downstream industry, the opportunity arises to reconsider the management regime of these sluice gates, for example to manage flushing of the loch to minimise impact of algal and cyanobacterial blooms. Such management changes could be considered as improved delivery of ecosystem services for the catchment as a whole, and hence potentially be the subject of a Payments for Ecosystem Services scheme[2]. The potential for such schemes is being explored through a Scottish Government funded project, PESLES. A recent report [3] has shown the potential for early summer flushing of Loch Leven to reduce the intensity of late summer algal and cyanobacterial blooms. The mechanism to increase flushing is to modify management of the exit sluice gates. This report demonstrates the potential for use of the hydraulic modelling software package HECRAS to identify suitable changes in gate management using retrospective analysis of inflow, water level and gate management data. Linking with a forecast based hydrological model, as has been done for the Lunan Water in Angus as part of PESLES, would enable such management to take place in a pro-active mode.

Materials and methods

Loch Leven

Historic and geographical information

Loch Leven is a large, shallow, eutrophic lake with a surface area 13.4 km^2, mean and maximum depths 3.9 m and 25.5 m, respectively, and an average volume of about 50,000,000 m^3. The catchment comprises 4 main inlet streams, the North and South Queich, the Gairney Water and the Greens Burn. The stream network and Loch are shown in Figure 1.

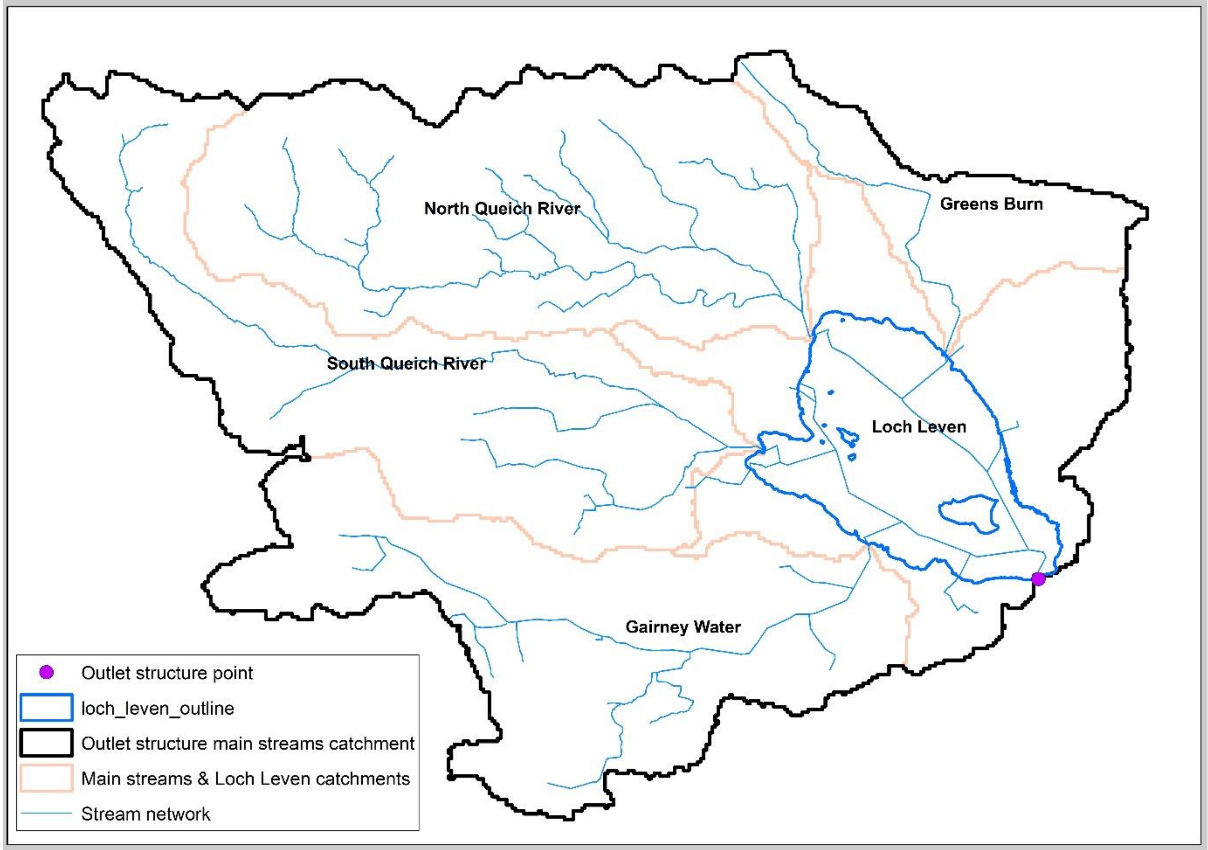

Figure 1. Loch Leven catchment and subcatchments with stream network

Hydrometric data

Daily inflow data are available from the National River Flow Archive for 3 of the inlet streams (see Table 1) The NRFA also provides data for the River Leven over a 3-fold larger catchment area.

The outlet sluice gates and their operation are very well documented as described in [4], with sluice gate management, water level data and outlet flows from 1851-1973 available (May, L., pers. comm).

Source of data	Site	NRFA Station	Grid Reference	Catchment/water body Area (km²)	Measurement	Period
UK National River Flow Archive	South Queich at Kinross	17008	NO1180901570	33.6	Daily discharge	1988-2019
UK National River Flow Archive	North Queich at Lathro	17015	NO1150304113	23.1	Daily discharge	1987-2019
UK National River Flow Archive	Greens Burn at Damley's Cottage	17018	NO1566304025	10.5	Daily discharge	1994-2019
	Gairney Water and unmetered catchment			77.4	none	
CEH (Linda May)	Loch Leven			13.4	Daily stage	1851-1973, 2004-2005
CEH (Linda May)	Loch Leven outlet			158	Daily discharge and sluice gate data	1851-1973, 2004-2005
UK National River Flow Archive	River Leven	17002	NO368005	424	Daily discharge	1972-2015
See: https://nrfa.ceh.ac.uk/data/station/info/17008 etc						

Table 1. ***Table 2. Sources of data for hydrological inputs and calibration***

Schematisation of catchment flows and loch storage using HECRAS

The hydraulic modelling software package used was HECRAS 5.0.7 [5]. Loch Leven was modelled as a storage area of 13.4 km^2, with a hypsographic curve as shown in Figure 2 (May,L., pers.comm). Instead of modelling each stream inflow, these were represented by a single inflow via a nominal trapezoidal channel with a bed level at 106.0 m above sea level and 20m wide at its base. A similar outlet channel was assumed, and the 4 sluice gates were inserted as inline gated structures with dimensions as described in [4]. See Figure 3. The invert level of the gates is 106.43m, the maximum height of each opening is 1.4m and the width of each gate is 2.718 m. Each gate was modelled independently as a broad-crested weir with sluice discharge coefficient of 0.7m, weir coefficient of 1.67 and submerged orifice coefficient of 0.8.

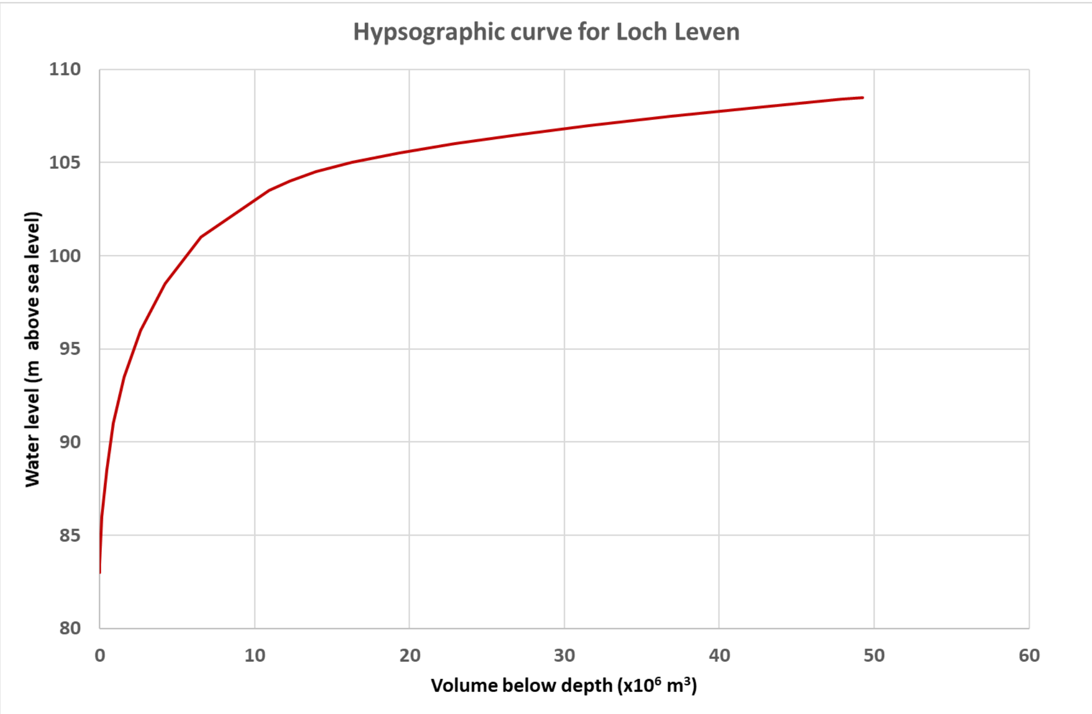

Figure 2. Hypsographic curve of loch storage versus depth

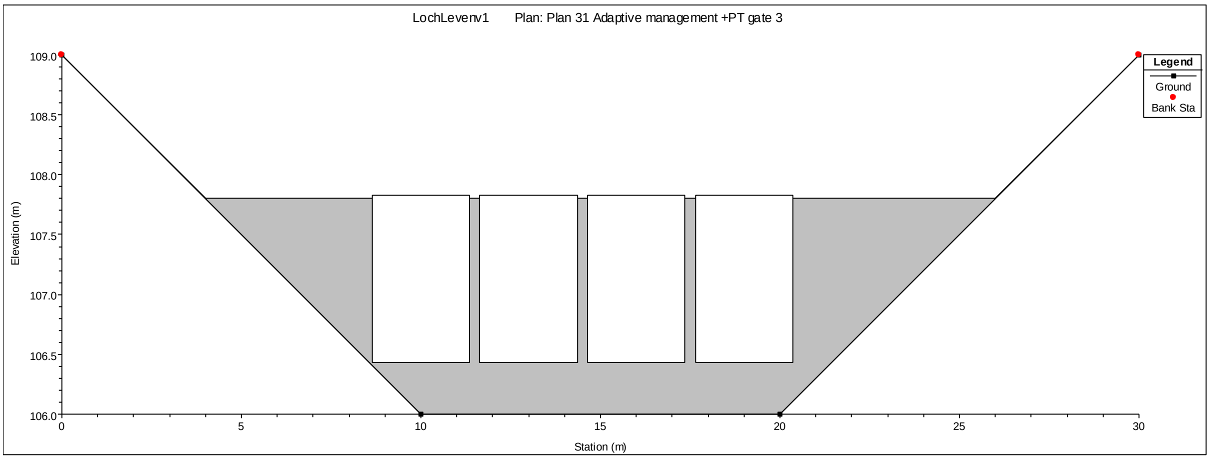

Figure 3. Representation of sluice gates on the outlet of Loch Leven for HECRAS modelling

Targeted changes in management

The report [3] which forms the immediate background to this report, as part of the Scottish Government funded PESLES project, describes the modelling of algal and cyanobacterial blooms in Loch Leven for 2005, using the PROTECH model [6]. It shows that extra flushing of the loch in early summer can achieve reduced levels of algal and cyanobacterial blooms in late summer. A summary of some of the scenarios simulated is given in Table 2. Our objective in this report is to demonstrate, through a few examples, that achieving such changes in flushing regime are feasible, by modifying gate management.

		Flushing scenario					
		x1.05 & 10 days	x1.05 & 20 days	x1.1 & 10 days	x1.1 & 20 days	x1.15 & 10 days	x1.15 & 20 days
Start date	Baseline	0%	0%	0%	0%	0%	0%
	Day 160	-28%	-31%	+9%	+1%	-24%	+18%
	Day 170	-37%	-37%	-26%	-35%	-28%	+4%
	Day 180	-2%	-37%	-39%	-38%	-37%	-1%
	Day 190	-2%	-2%	-37%	-39%	-39%	-37%
	Day 200	1%	-2%	-3%	-1%	-1%	+1%

Table 2. Example of simulated changes in maximum cyanobacterial chlorophyll a concentrations for 2005 under different flushing regimes for Loch Leven in early summer, compared with actual flushing regime.

Results and Discussion

Generation of inflow data series

The composite inflow data series comprised area-adjusted flows from the monitored sub-catchments, with the S.Queich used to describe the non-monitored catchment area, and Rainfall-PE used to describe net precipitation on the Loch surface. The results for 2005, compared with observed outflow and loch water levels, are shown in Figure 4.

Calibration of HECRAS for 2004-5

The long term data set of gate openings (1851-1973) specifies the number of gates open on each day, as well as the height of opening, but unfortunately the data on number of gates is lacking for 2004-5. We only know the daily height of the gates above the sills, but not the number of gates in operation. The principal task in this preliminary calibration of HECRAS has therefore been to estimate the missing time series of the number of gates open for 2005. We ran HECRAS from Jan 2004 assuming 2 gates were open, and aimed to get agreement between observed and simulated water levels by the beginning of 2005. The restart file for Jan 2005 could then be used to explore the impact of having a fixed number of gates open (1, 2 or 4) during 2005. Observed time series of Loch Leven water levels for 2005, compared with simulations assuming 1,2 or 4 gates are open (with gate openings as shown in Figure 4) are shown in Figure 5. A "calibrated" regime of gate openings which led to reasonable agreement with the observations, and the simulated water levels resulting from this calibrated gate opening regime, is also shown.

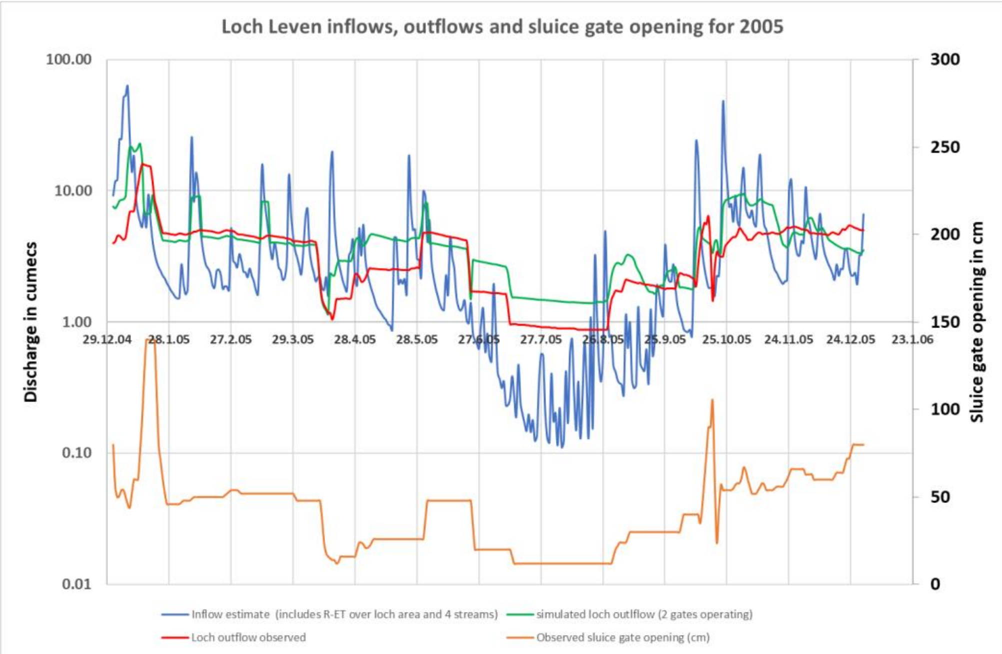

Figure 4. Composite inflow data for hydraulic modelling of flushing and water levels in Loch Leven for 2005, together with measured loch outflow and gate opening data (right hand axis). The outflow modelled using HECRAS, assuming 2 gates are operating is also shown. ..\..\hecras\Loch leven data\Loch leven flow and levels.xls

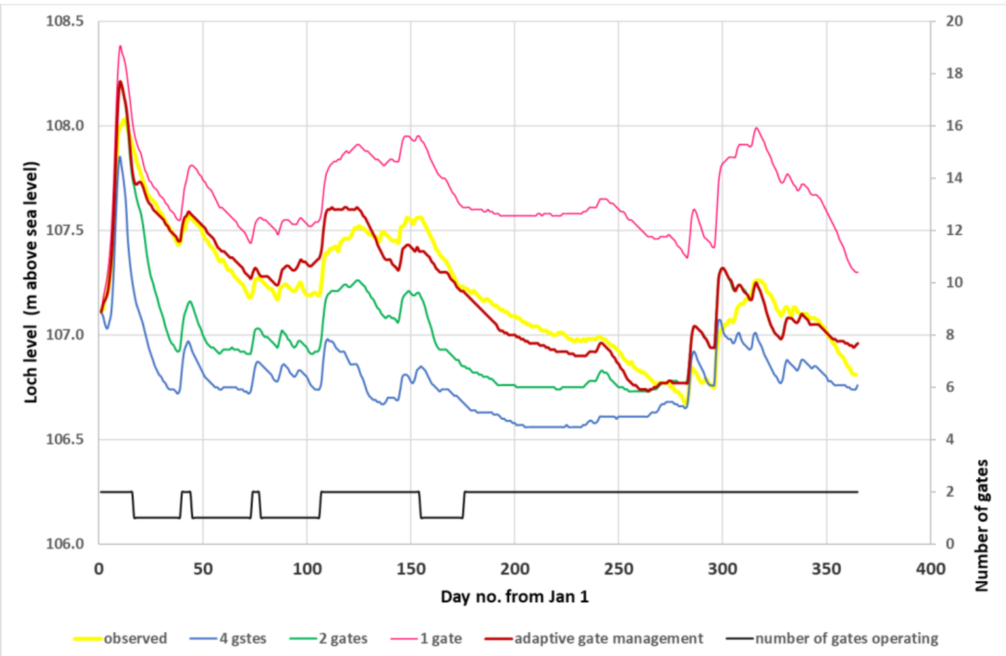

Figure 5.Observed time series of Loch Leven water levels for 2005, compared with simulations assuming 1,2 or 4 gates are open, with gate opening as shown in Figure 4. The assumed regime of gate openings which led to the observations, and the simulated water levels resulting from this regime, are also shown.

Management of gates to generate increased flushing

We considered 3 potential modifications to the "calibrated" gate opening regime to achieve the optimum scenario as shown in Table 2, namely 15% additional flushing for 20 d from day 190. Results are shown in Figure 6. In Figure 6a, The "flushing gate", gate 3, was opened to the same aperture as gates 1 and 2, for 20d from day 190 (9th July). This led to an increase in the mean weekly flushing rate up to 15% for 10d, but only beginning from 21 July (day 202). Given that Table 2 shows that delaying the date of initiation of flushing is critical, it is important to initiate a flushing regime earlier. In order to achieve a weekly average flushing rate increase of 15% by day 190, it was necessary to start modifying the management on day 180. Figure 6b shows the increase in flushing, when gate 3 was opened to the same aperture as gates 1 and 2, but for 20d from day 180 (29th June). This achieved the targeted 15% increase in weekly flushing rate, but was over 25% for an extended period. Reducing the period of opening of the flushing gate to 10d, and opening from day 180, achieved the required result as shown in Figure 6c.

Note that the extra flushing during the early summer was counterbalanced by lower flushing (and slightly lower water levels) later in the summer, but by this time the nutrient cycling processes in the loch which influence algal and cyanao-bacterial growth regimes, have already been set.

This is as far as we can go, in this preliminary study, with exploration of options for management, and setting rules for gate management. However, HECRAS software enables rules for gate management to be programmed to target specific objectives. Further work would include developing such rules, as well as improved calibration of inflows based on long term rainfall-runoff records, estimation of groundwater contributions based on baseflow data and use of site-specific stage discharge relationships derived by [4] for the outlet structure.

Conclusions and Recommendations

- This proof of concept study shows that it is possible to retrospectively identify modifications of gate management regimes to delivered targeted changes in Loch flushing rate and timing.
- Such changes could have significant benefits in managing the intensity of algal and cyanobacterial blooms in late summer.
- Further work on calibration is required, using known, rather than estimated gate numbers in operation.
- Developing a rule base for proactive management would be the target of such further work.
- This would be enhanced by the development of predictive models of inflow to the Loch, based on Met Office forecasts and rainfall-runoff relationships.
- The approach described could form the basis of a Payments for Ecosystem services scheme that would help finance the additional management inputs required by those responsible for managing outlet structures in keeping with current, rather than historical catchment stakeholder requirements.

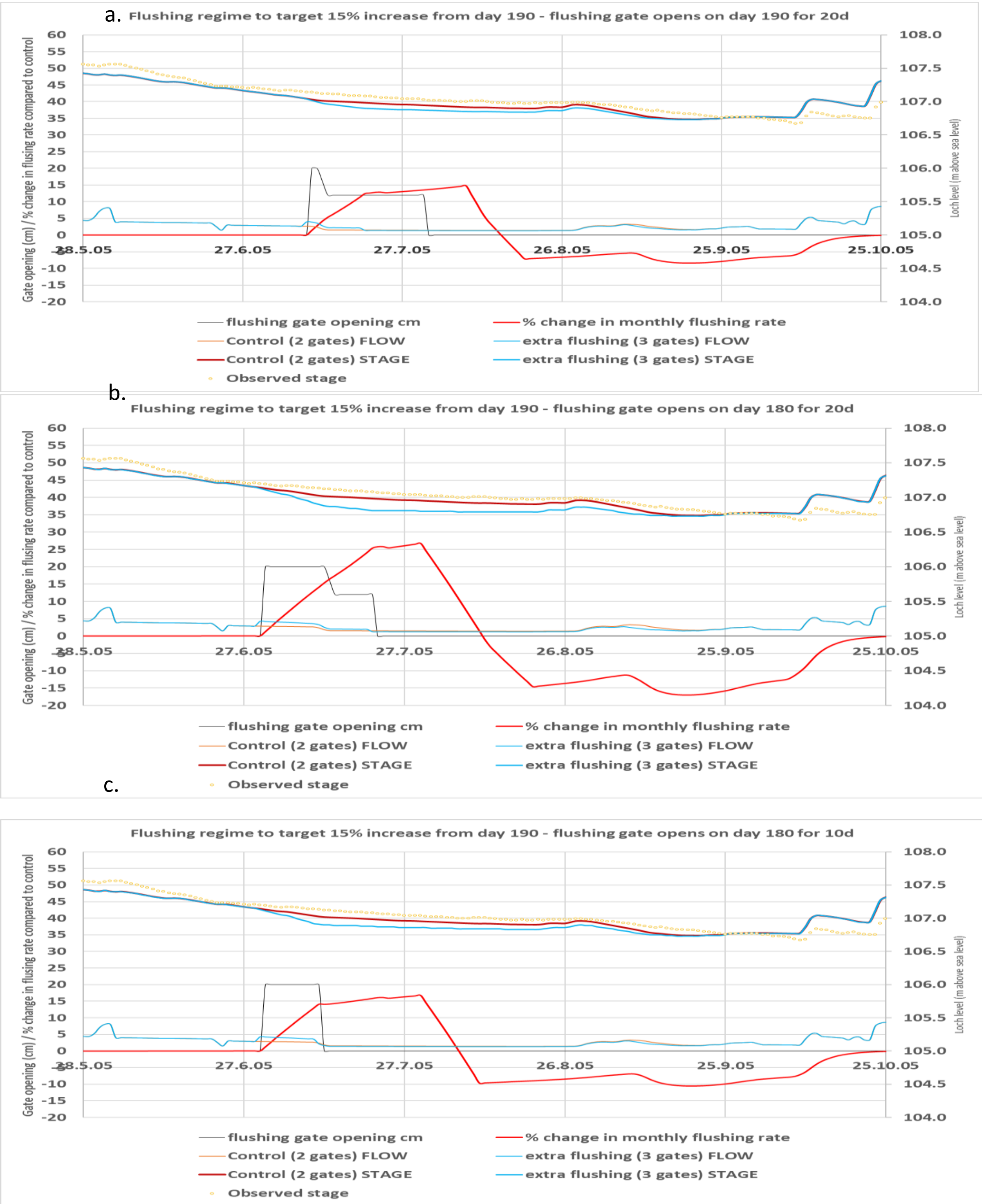

Figure 6. Changes in Loch Leven flushing rate and water levels as a result of operating the flushing gate for 3 scenarios.

References

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Acknowledgements

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